Paleoweathering record and paleosurfaces in the Bohemian Massif, Central Europe and Fennoscandian Shield, Northern Europe.
A basis for East-West comparisons

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Géologie de la France, 2003, n° 1, 53-56.

Key words: Paleoweathering, Mesozoic, Cenozoic, Erosion surfaces, Paleosurfaces, Central Europe, Bohemian Massif, Fennoscandian Shield.

Introduction

Bohemian Massif in Central Europe and the south-central part of the Fennoscandian Shield, although geographically distant and geologically belonging to different provinces, share some characteristics which have made both areas very suitable for paleoweathering and paleosurface studies. The former has long been known for its extensive occurrence of weathering residuals whose ages go back to various periods of the Mesozoic and Cainozoic. Especially, kaolinitic products of granite and gneiss weathering are widespread and have made the Bohemian Massif one of the key areas for studying kaolins in general (Kužvart and Konta 1968). On the other hand, the latter shows a pattern of characteristic landscape types, which neither coincides with lithological boundaries nor can it be ascribed to the diversity of glacial erosional processes. This spatial pattern has recently been interpreted, with the aid of sedimentary cover rock distribution, as a mosaic of paleosurfaces of different ages (Lidmar-Bergström *et al*., 1997, 1999). Furthermore, many of the landscape types distinguished in Fennoscandia are associated with certain types of weathering residuals and hence, their potential as 'reference surfaces' in identification and correlation of paleosurfaces has emerged.

These circumstances raise the possibility that findings and conclusions drawn from the studies of the two above named regions may also be valid elsewhere. Hence, they are offered here in the hope that they may assist in European-wide, east-west comparisons, and contribute to the deciphering of long-term landscape evolution of European oldlands, as well as to the comprehensive understanding of conditions necessary for the origin and survival of paleolandscapes in general.

Paleoweathering record

Although there occurs a remarkable diversity of weathering mantles in both areas, two distinct types of paleoweathering can be distinguished at the most general level. These are: (1) residual mantles arising from deep-reaching and thorough weathering, and (2) geochemically immature products of near-surface alteration. The former include kaolinite-rich mantles developed on basement rocks whose thickness may be from 15-20 m to as much as 100-120 m in certain parts of the Bohemian Massif, as well as lateritic-like products of weathering of basalt or serpentinite. The other category is that of grus and arenaceous residuals, extensively developed on crystalline rocks. They usually form a discontinuous mantle interspersed with bedrock outcrops, and are from 1-2 m to 15-20 m thick, but depth of grus in excess of 10 m is rare. The paleoweathering record *in situ* is supplemented by the sedimentary record from adjacent basins (North Sea, Mid-European Trough, Carpathian Foredeep, tectonic grabens inside the Bohemian Massif), which demonstrates that deep weathering was one of the key processes in landscape evolution of Central and Northern Europe in the last 100 Ma at least (Migoñ and Lidmar-Bergström, 2001).

These two broad categories of weathering mantles have usually been interpreted as indicative of contrasting environmental conditions during the periods of weathering (cf. Bakker, 1967; Kužvart and Konta, 1968). Kaolins and laterites would have formed in a hot and humid climate, typical for the present-day low latitudes, whereas mineralogical immaturity of sandy and grus residuals would have pointed to a much less aggressive environment, warm to cool temperate. In accordance with this interpretation, these two major paleoweathering categories have been linked with different periods of geologic time,

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corresponding to ‘greenhouse’ and ‘icehouse’ epochs. Kaolinitic and lateritic mantles are ascribed a Mesozoic or early Tertiary age, and in many places this dating is broadly confirmed using stratigraphic approach, namely kaolins typically occur beneath sediments of Upper Cretaceous, Eocene to Miocene age. Progressive climate cooling from the mid-Tertiary onward is believed responsible for the general change in weathering style and the appearance of grus from at least the Middle Miocene. However, ages of grus are in most places very poorly constrained or unconstrained at all as overlying deposits commonly date back only to the latest Pleistocene.

Analysis of distribution of both types of mantles in two study areas reveals certain specific features. In the Bohemian Massif products of advanced weathering are most widespread within areas subject to long-term subsidence such as fore-mountain basins, tectonic grabens and down-faulted intramontane basins. Much less common is their presence on elevated surfaces of low relief. Grus, by contrast, is typical for upland areas and may occur in various topographic settings, including watershed flats, moderately inclined slopes and slope/valley floor junctions. It is also widely present in inselberg landscapes. In the southern part of Fennoscandia there occurs a clear zonality in the distribution of weathering products. Thick kaolins are typical for hilly landscapes of southernmost Sweden, whereas arenaceous mantles occur quite extensively within less differentiated relief of south-central to central Sweden. In addition, clayey fissure fillings have been reported from a number of places along the west and south coast of Sweden.

Paleosurfaces

Two distinctive types of paleosurfaces have been identified within the Bohemian Massif and the Fennoscandian Shield.

(1) Surfaces whose subaerial development has been interrupted by burial by younger sediments or, locally, by lava flows. Burial may have been triggered by regional subsidence, or by sea level rise, or both. Many of buried surfaces have subsequently been exhumed, either completely or partially. Extensive exhumed surfaces exist in Fennoscandia and date back to the late Precambrian (Sub-Cambrian peneplain) and Cretaceous (Sub-Cretaceous etchsurface). Partially exhumed sub-Cretaceous relief is present in the Bohemian Massif too. Exhumed surfaces are characterised by specific suites of paleoweathering products, e.g. thick kaolins within the sub-Cretaceous relief.

(2) Surfaces of low relief present within mountain ranges and massifs which have been subject to relative uplift in late Tertiary to Quaternary. These include mountainous areas in the outer parts of the Bohemian Massif and the axial part of the Scandinavian Mountains, where an extensive ‘Paleic surface’ occurs. Gently rolling watershed surfaces stand in marked contrast to deeply incised valleys and evidently point to relatively recent replacement of planation processes by fluvial incision. These surfaces are often referred to as Early Tertiary paleosurfaces, but they typically bear neither weathering mantles nor sedimentary cover remnants which might confirm such age assignments. On the other hand, geologically younger grus may occur widely.

In addition, in Fennoscandia there occur rock-cut landscapes, undulating or hilly, which do not fall into any of the above-named categories but are evidently preglacial. The widespread South Smaland Peneplain in south Sweden serves as an example. There are no obvious indications of their very ancient ages and quite a wide presence of arenaceous mantles is consistent with their active development as late as immediately prior to the ice ages. Similar ‘preglacial’ landscapes occur in those parts of the Bohemian Massif, which are located within the extent of the Scandinavian ice sheet in the Pleistocene. Further south, many undulating and hilly landscapes carry a cover of grus too, but because of their location outside the limit of glaciation, they are better considered as actively evolving rather than inherited, even if their geomorphic history has ancient roots.

Problematic issues

A number of issues emerges from the simultaneous analysis of paleoweathering record and paleosurfaces. These are related to paleoenvironmental interpretation of weathering residuals, the meaning of paleosurfaces and the conditions of paleosurface survival.

Traditional view linking kaolinitic and ferrallitic weathering with warm and humid climate of Mesozoic and Early Tertiary, and arenaceous mantles with the cooler Late Tertiary period, fails to explain all peculiarities of distribution of weathering residuals, both in time and space. An apparent trend from more to less advanced weathering does not only reflect climate change, but it is also broadly consistent with tectonic history and induced surface stability changes. Sandy/grus mantles in particular are proposed to be indicators of weathering profile lowering and general surface instability which prevents the profiles from attaining mineralogical maturity. In the Bohemian Massif there are areas where kaolins and grus mantles co-exist and their distribution pattern is such that the former occur within subsided areas and, less often, beneath high-altitude undulating plains, whereas grus typifies higher ground or dissected relief separating higher and lower paleosurfaces. Examples of this kind of situation include Fichtelgebirge (Peterek, 2001), SE margin of the massif south of Brno (Ivan and Kirchner, 1994), and the Sudetes Mountains in the north-east (Migoñ, 1999a). On the other hand, however, it is likely that grus in southern Sweden reflects mainly the climatic signal.

Paleosurfaces in both the Bohemian Massif and the Fennoscandian Shield demonstrate that it would be wrong to equate them with planation surfaces, as has often been implicitly assumed, and that the concept of paleosurfaces is to be refined. Paleosurface is a landscape whose development happened to be interrupted by burial or significant surface uplift at a rate exceeding any rates of surface lowering, and this landscape could be anything from a perfect plain to multi-convex etchsurface, tower or cockpit karst. Respective examples include the Sub-Cambrian peneplain of Sweden, Sub-Cretaceous hilly landscapes in southernmost Sweden, Moravian Karst in the east Czech Republic and Franconian Alb tower karst in northern Bavaria. In south Sweden it has been shown on the example of the Sub-Cretaceous landscape that its spatially variable geomorphic characteristics depend mainly on the duration of exposure to deep weathering (Lidmar-Bergström, 1995), whereas in the Sudetes and its foreland lithology and structure seem to play a significant part, so that different basement complexes support different types of paleosurfaces (Migoñ, 1999a).

There are two principal scenarios possible of paleosurface survival, which can be shown as follows.

(a) ‘primary’ surface → burial → buried paleosurface → exhumation → exhumed paleosurface → post-exhumation modification;

(b) ‘primary’ surface → uplift → dissection → paleo-features surviving on divides → upland paleosurface → reduction in extent due to ongoing dissection and slope lowering.

It seems that the role of burial and exhumation did not receive due attention in the past. The search for paleosurfaces conceptually followed the classic model of denudation chronology, being mainly concentrated on the recognition of ‘uplifted peneplains’. In fact, many of the ‘Tertiary peneplains’ identified in this way are highly conjectural and usually no clues to their ages are available. Whether these elevated surfaces are indeed ancient landscape facets, remains an open question. By contrast, long neglected buried and exhumed surfaces of well documented ages are rather common and multiple episodes of burial/uncovering are envisaged for both the Fennoscandian Shield and many parts of the Bohemian Massif. In particular, exhumed Cretaceous paleosurfaces are likely to be more widespread than thought before, a view confirmed by recent datings of kaolins in East Germany (Gilg, 2000). Given the undetermined age of most kaolin *in situ* deposits in the Bohemian Massif, it cannot be ruled out that some of those usually attributed to Early Tertiary weathering, can actually be of Cretaceous age.

Conclusions

The evidence from the Bohemian Massif and the Fennoscandian Shield allows for the following conclusions, potentially important for east-west comparative studies.

- pre-Upper Cretaceous weathering residuals are quite widespread in both areas, as are associated paleosurfaces of etch type, including deeply karstified terrains;

- ages of many *in situ* kaolin residuals, traditionally considered as early Tertiary, are in fact unconstrained and they may be of either earlier or later date;

- widespread arenaceous mantles (grus) have probably formed in the response to growing tectonic and geomorphic instability towards the end of the Tertiary and are poor paleoclimatic indicators;

- geomorphology of paleosurfaces is highly variable, depending on the lithology and structure involved, duration of exposure, and style of deep weathering.

It remains an open question whether paleosurfaces of different ages may be identified by weathering products associated with them. In the southern part of the Fennoscandian Shield distinctive types of paleoweathering correlate rather well with specific landscape types, but no comparable situation seems to exist in the Bohemian Massif.

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